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Pitch Contrast in Meter Perception

Nigel O. Lay
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Nigel O. Lay entitled "Pitch Contrast in Meter Perception." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

John C. Malone, Major Professor

We have read this thesis and recommend its acceptance:

Howard R. Pollio, Mark Hedrick

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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PITCH CONTRAST IN METER PERCEPTION

A Thesis
Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Nigel Obadiah Lay
May 2008

Dedication

This thesis is dedicated to my grandparents, Theodore and Selma Shapiro, who inspired my love of learning, my love of music and my scientific curiosity.

Acknowledgments

I wish to thank those who gave me assistance during my graduate study. Thanks to Dr. Stephen Handel, who conferred with me by telephone despite his retirement. Thanks to Dr. Thomas Graves for tutoring me in the use of the *Reason* software and for having countless conversations with me over plates of enchiladas about how to carry out this research, deal with the data and keep working when I thought all was hopeless. Thanks are due to Dr. Howard Pollio, who inspired me to continue to think creatively. I wish to thank Dr. Mark Hedrick for allowing me the use of his laboratory to run the experiment and for asking great questions. Thanks also to Dr. John Malone, under whose mentorship I have learned more than I can say. He kept me around, even though I'm "weirder than a three-headed duck."

Abstract

The role of large pitch contrasts in meter perception of three-pulse-train polyrhythms was investigated. Subjects were presented with several polyrhythmic configurations having both small and large pitch contrasts and were asked to tap the meter, or beat. Some subjects preferred meters based on the lower-pitch and slower-progressing pulse trains, while others preferred unit-based meters. Results revealed that three-pulse-train polyrhythms with large pitch contrast do not result in notably different meter perceptions from those with smaller pitch contrast. These results support previous findings which showed that meter is determined by multiple factors, such as pulse-train pitch and relative pulse-train tempo.

Preface

Seeds from which this project developed lie in some areas of interest which may not seem on the surface to be related directly to the project itself, and in some that surely do. This author has long been intrigued by rituals which take place in shamanic cultures. These rituals and ceremonies invariably include drumming, most of the time performed by the shaman his- or herself. A shaman's drum is considered a very important and powerful tool and is a means by which ecstatic and trance states are potentiated.

This interest in shamanic cultures and ecstatic experiences extends also to other (sometimes non-shamanic) contexts in which ecstatic experiences may occur, such as drug use/rituals and religious ritual, including song and dance.

More recently, the intriguing phenomenon of the synchronization of physiological activity with external rhythmic stimuli, such as flashing lights or recurring tone pulses, has been added to this author's interests. This can be related to the James-Bain Law of Diffusion and dynamogenic effects. As James (1890, Ch. XXIII) wrote, "A process set up anywhere in the centres reverberates everywhere, and in some way or other affects the organism throughout, making its activities either greater or less."This topic, and its possible relationship to hypnotizability and a person's potential for ecstatic experience, was the subject of a class project for this author.

Another, more personal, realm of experience informed the development of the project related in these pages. That is the experience of listening to music, which is one of this author's favorite activities. Complex rhythms are enjoyable, and part of the fun is in finding a regular beat, or meter, in a piece of music which can be used to stabilize the rhythmic pattern, or to provide a way of perceptually organizing the rhythm. This "metering" activity becomes particularly salient in listening to jazz, with all of its characteristic syncopation, and in listening to some of the music of Frank Zappa, especially pieces in which musicians are playing in multiple time signatures. Finding a meter sometimes enhances the enjoyment of listening to a piece of music.

Oliver Sacks, the well-known neurologist and author, was climbing a mountain in 1974. After reaching the peak of his hike and beginning his trip back down, he lost his footing and fell over a cliff. His left leg was badly injured and lifeless. Since he couldn't walk and was alone, he continued the descent by scooting on his back, pushing with his hands. Soon, exhaustion overtook him, but he knew that if he didn't keep moving the Norwegian cold would end his life during the night. Music saved Sacks. He would think of or chant a song, using its rhythm to "row" himself down the mountain. "I found myself perfectly coordinated by this rhythm–or perhaps subordinated would be a better term: the musical beat was generated within me... I was *musicked* along." That evening, Sacks reached the base of the mountain. [This is a summary of an account which appeared in Seed magazine (Lehrer, 2007).]

This project is the product of eclectic interests, with deep roots in a personal passion for music.

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NOMENCLATURE

Cross-rhythm: illustrated by taps to all of the elements in more than one pulse train in a polyrhythm

Meter: a regularly recurring event in a rhythmic sequence which serves to provide a structure to the pattern of which it is a part

Polyrhythm: a simultaneous occurrence of two or more rhythmic patterns (“pulse trains”) progressing at different rates

Pulse Train: a series of regularly recurring, isochronous tones of the same frequency

Chapter 1

Introduction and Literature Review

Time, said Augustine, did not exist until the Creation. In addition, time is subjective, and we are always experiencing the present. Time future and time past only exist as thought of in the present, as in expectation and memory. The fact of the subjectivity of experience was, for Augustine, evidence for self-existence. Knowledge is gained indirectly, for the mind has direct contact only with itself; experiences come from within the mind (Watson & Evans, 1991, pp. 114-117). His conception of time informed his ideas about the nature of mind and experience.

Augustine would agree that one way we experience time is through rhythm. A great deal of research has been done concerning rhythm, but there has been comparatively little research conducted concerning polyrhythms. (A polyrhythm can be described as a simultaneous occurrence of two or more rhythmic patterns progressing at different rates.)

Western music, historically, has been known for melodic sophistication, coupled with a dearth of rhythmic depth. Simple rhythms are characteristic of music of this part of the world, while traditional music from Eastern and African cultures has tended to display more dense, syncopated rhythms. The development of blues and jazz music around the beginning of the 20th Century in the United States of America began to change this, but the emphasis on rhythm in these types of music does not begin to approach the level of rhythmic sophistication of traditional African and Indian music. Within the large body of research into rhythm, only a small amount has dealt with the perception of meter. This holds for polyrhythms as well. Previous work with polyrhythms (e.g., Handel and

Oshinsky, 1981; Handel and Lawson, 1983) sought to establish an understanding of the perception of meter in polyrhythmic sequences in order to work toward a comprehensive theory of rhythm. The purpose of this research is to further investigate the effect of pitch differences in the perception of the meter of syncopated auditory polyrhythms.

Literature Review

Issues

E. G. Boring (1942) described the contributions of Wundt, Dietze, Bolton, Koffka, Meumann, R. MacDougal, Woodrow, Titchener and Ruckmick. He has described rhythm research (1942) as having been concerned primarily with three issues. The first of these issues is that of the "range of consciousness," beginning with Wundt near the end of the 19th Century. Wundt used the example of rhythmic groups to illustrate his idea of the *Blickpunkt*, or focus of attention. People tend to perceive a series of beats as grouped into units. Others, including Dietze in 1885, Bolton in 1894 and Koffka in 1909, attempted to measure the range of consciousness by studying perceptual grouping.

The second issue addressed in rhythm research concerns the psychophysics of rhythm. Research in this vein has attempted to study what decides the perception of rhythm by altering the physical characteristics of stimuli. Bolton, Meumann, both in 1894, R. MacDougal in 1903 and Woodrow in 1909 all examined auditory rhythms in this way. Intervals between perceived groups tend to be judged as longer than intervals within groups, with a variety of factors influencing how this occurs and how perceptual groups are created. MacDougal established "indifference points," or points at which the perceived rhythm is destroyed, by altering durations of intervals within his series.

Woodrow followed this method in his research.

Third, the issue of kinesthesis has been investigated. The question here is whether some kind of movement is necessary in order for rhythm to be perceived. Everyone investigating rhythm, according to Boring, has noticed that some type of bodily movement tends to accompany auditory rhythm. Specifically, people tend to "keep time" by tapping a toe or finger, or by nodding the head. Titchener advanced the kinesthetic view in 1909, but Ruckmick, in 1913, aided in its fall from favor. According to Titchener, the separation of auditory units (the "core") into groups depends on kinesthesis. Ruckmick argued that while a physical movement may initially be necessary for rhythm perception to occur, movement isn't required to sustain it; the kinesthetic component may cease, allowing a purely auditory perception to continue. Boring stated that the issue may be one of definition: pattern perceptions occur both with and without kinesthesis, but should our conception of rhythm be defined exclusively as perceptions accompanied by kinesthesis? A definition such as this, Boring said, is too constrictive and would force one to consider as *cessations of rhythm* those perceptions whose kinesthetic accompaniment has ceased (Boring, 1942).

Rhythm

Rhythm, as discussed here, may be thought of as the temporal organization of sound. Bengtsson (1961), discussing rhythm and tonality in Western music, pointed out that things which we describe using our languages of "harmony" and "rhythm," as if they are separate, actually are always affecting one another; the separation is false, and so our way of discussing music is misleading, or at least inadequate. Tonality cannot be discussed at all without mention of rhythm. The research reviewed below respects (some of the time, at least) this condition.

One approach used to study rhythm is to use patterns with multiple lines (polyrhythms) to ascertain how rhythm is perceived (e.g., Handel & Lawson, 1983; Moelants & van Noorden, 2005). A polyrhythm can be thought of as the simultaneous occurrence of two or more rhythmic patterns – pulse trains – proceeding at different rates. A pulse train is a series of regularly recurring, identical elements. This approach is psychophysical, for it is characterized by changing the physical attributes of stimuli in an effort to learn about perception.

Many factors influence the choice of an experimental paradigm, one of which is how well the chosen phenomenon is simulated. Using polyrhythms allows the experimenter to increase realistic complexity while maintaining the control required by an experiment. Methodology can affect the experimenter's ability to address the issue effectively. Tapping has been used because it is very commonplace, easily performed and highly transparent, meaning that one can focus on what is being responded to without being distracted by the act of tapping. The high level of perceptual freedom afforded by this act is essential because of the many interpretations made possible with polyrhythms. (These interpretive possibilities will be addressed below.) The goal for the researcher in this situation becomes to identify the different strategies of interpretation and how variation affects rhythmic interpretation (Handel, 1984).

Timing and Meter

Meter is difficult to define and is not a concept on which there is consensus. Some oppose restricting meter to a regularly recurring event (Berry, 1976), arguing that it is always mutable, while some use the concept of meter in the same way that others use "beat" or "pulse." Meter, as it is conceived here, is rather like the latter concept, that is, a regularly recurring event in a rhythmic sequence which can serve to give structure to and make sense of the rhythm. In order to distinguish between rhythm and meter, one may think of a person in a marching band. This person is playing the rhythm on an instrument while marching the meter.

Empirical Findings on Perception of Rhythm

Polyrhythms

Oshinsky and Handel (1978) asked whether meter perception is absolute or relative with respect to tempo, or overall presentation rate. (Keep in mind that meter is perceptually defined, while tempo is a physical characteristic of a rhythm.)

In this experiment, a 3×4 polyrhythm–that is, a polyrhythm composed of a simultaneous three-pulse train and four-pulse train–was presented at varying tempi, ranging from 0.96 s to 2.4 s per pattern repetition. Pitch/frequency arrangements were varied also. Sometimes both pulse trains were presented at the same frequency (either 507 Hz or 486 Hz), and sometimes the pulse-train frequencies differed. When the frequencies differed, one pulse train was presented at 440 Hz (musical A4) and the other was presented at 586 Hz (D5). This difference represents the musical interval of a fourth - five semitones - which is considered a consonant, or at least, non-dissonant, interval. Two timbre conditions were created also, with pulses having either a rapid or gradual amplitude attack and release. Subjects were instructed to tap along to the meter of each polyrhythm as they listened to it.

Subjects responded in three ways: they tapped to the three-pulse train, the four-pulse train, or to the co-occurrence of both pulse trains, that is, once per pattern repetition. Interestingly, though, meters reversed at one repetition rate. For instance, a subject may have tapped to the three-pulse train at all but one tempi, switching to the four-pulse train at that one tempo. Reversals tended to occur at intermediate rates, and the timbre condition informed at which rate the reversal occurred. Timbre also informed which meter predominated, with the three-pulse-train meter dominating in the rapid timbre condition.

Some subjects showed a pitch preference; no meter reversal was observed for these individuals. They usually preferred the high pitch in the rapid-timbre condition.

Oshinsky and Handel concluded that rhythm perception is dependent on tempo and timbre.

<u>Greater complexity</u>

In 1981, Handel and Oshinsky followed up on their 1978 paper by increasing the number of conditions. This time, they used five polyrhythmic configurations and a larger array of presentation rates, ranging from 0.3 s to 4 s per pattern repetition. Frequency conditions were: a no-contrast condition, with all elements at the same frequency, and a contrast condition, with pulse-train elements separated by a musical fourth. Subjects were presented with the polyrhythms and were asked to tap the meter.

Three response classes were identified. One class, meter responses, was the most popular; this response class consisted of subjects following every element in one pulse train. The other two classes were (1) unit responses, in which subjects tapped once per pattern repetition, and (2) a way of responding which consisted of subjects tapping every second or third element in one pulse train. Responses in the latter class were counted as meter responses.

Also, clusters of subjects were identified, based on the "strategies" they employed. One strategy was to tap to elements of one pulse train, regardless of pitch, and the other strategy was to tap to the lower-pitch elements, without regard to pulse-train. Both of these response strategies are examples of meter responses.

Inter-element timing factors came in to play. For example, when subjects tended to prefer to tap to the faster pulse train in the 2×3 and 3×5 polyrhythms, this preference was not observed when inter-element intervals for the faster pulse trains were below 250 ms.

Some individual differences were noted, such as those seen with the 2×5 polyrhythm. One group of subjects preferred the five-pulse train overall, while a second group preferred the two-pulse train overall. This was reflected in the repetition rates at which each group switched their preferences. Those who preferred the five-pulse train switched to the two-pulse train at a faster presentation rate than did those who showed an overall preference for the two-pulse train.

This pattern for the 2×5 polyrhythm also illustrates the other side of the timing issue; inter-element intervals may have been too long in the slower presentation rates to allow the two-pulse train to serve as the meter. In more perceptual terms, elements/pulses may have been so temporally separated that subjects were unable to perceive them as a structure.

It was noted that polyrhythm configuration can affect meter interpretation, as more complex configurations allow more interpretations.

Handel and Oshinsky concluded that meter interpretation depends on "higher order perceptual interactions among the two pulse trains," not on simple factors. The function of meter, they said, may be to provide a background support for the foreground melodic structure, so it would make sense for the slower pulse train to serve as the meter, within timing constraints.

Contextual interpretation

In 1983 Handel and Lawson reported that rhythm interpretation is contextual. This had been shown previously with respect to tempo (cf. Handel and Oshinsky, 1981), and Handel and Lawson extend the concept to other aspects of rhythm, such as polyrhythm configuration, pulse frequency and pulse duration.

In these experiments (there were five in this paper), both two- and three-pulse-train polyrhythms were used, and no restrictions were placed on subjects with respect to the way in which they responded. This means that cross-rhythms were allowed. Cross-rhythms are characterized by tapping to two or more of the pulse trains in a polyrhythm. Handel and Lawson argued that cross-rhythms and meter responses can be taken as opposite sides of the same organizational activity– that is to say, cross-rhythms are the melodic foreground, while meter is the background of a rhythmic structure.

Some methodological aspects were common to the five experiments covered in this paper. With the exception of experiment four, pulse length was half of the inter-element interval (also called "onset-to-onset interval"). The inter-element interval is the elapsed time from the beginning of one pulse in a pulse train until the beginning of the following pulse in that pulse train. So, if we have an inter-element interval of 70 ms, our pulse length will be 35 ms.

Subjects were presented with each polyrhythm twice: first, to listen, second, to respond. Each presentation lasted 15 s. Frequent breaks were given "to minimize fatigue" (Handel and Lawson, 1983).

Three response classes were identified in these experiments. They were: cross-rhythms, meter responses and unit responses. As mentioned above, cross-rhythms consist of taps to all of the elements in more than one pulse train, meter responses are taps to elements of one pulse train, and unit responses are taps to the coincidence of pulses in all pulse trains comprising a polyrhythm, that is, once per pattern repetition.

- Experiment 1

Handel and Lawson's first experiment dealt with the rhythmic interpretation of two-pulse-train polyrhythms. Pulse trains were presented either at identical frequency (507 Hz), or separated by the musical interval of a fourth, with one pulse train at 440 Hz (A4) and the other at 586 Hz (D5). Several presentation rates were used, and sessions lasted two hours.

Nearly all (98%) of the responses were cross-rhythms and meter responses, with cross-rhythms occurring more often at slower presentation rates. Handel and Lawson observed that, for meter responses, inter-element timing was the most important factor. Subjects tapped to a pulse train when its inter-element interval was in the window between 200 ms and 600-800 ms.

Polyrhythm configuration affected which pulse train was followed. Slower meters were tapped at faster presentation rates, and faster meters were tapped at slower presentation rates. For example, for the 3×4 polyrhythmic configuration, subjects preferred to tap the three-pulse train at faster presentation rates and the four-pulse train at slower rates. Yet, for the 4×5 polyrhythm, subjects tended to tap the four-pulse train at faster presentation rates, while preferring the five-pulse train at slower rates. Preference for the four-pulse train depended on which polyrhythmic configuration it was part of, so the configuration of the polyrhythm affected which pulse train served as the meter.

Responses were unambiguous when timing constraints (inter-element intervals between 200 ms and 800 ms) were met by only one pulse train, but when both pulse trains satisfied timing constraints, pitch became an important factor. When pitch cues were used to decide the rhythm, the low-pitch pulse train was always preferred. Configuration also played a part here, with pitch-based meters only occurring with polyrhythms composed of pulse trains with similar rates of progression–the 3×4 and 4×5 polyrhythms, for instance. (The similar rates of progression allowed both pulse trains to meet timing constraints.)

Handel and Lawson noted that very few individuals followed a consistent interpretation strategy, and they stressed the contextual character of rhythmic interpretation. Interaction among the aspects of each polyrhythm (timing/tempo, frequency of elements, configuration) and individual differences determined the responses obtained in this experiment.

• Experiment 2

In this experiment, Handel and Lawson investigated three-pulse-train polyrhythms.

Three frequencies were used to construct the polyrhythms in this experiment. These were, 252 Hz (C4), 330 Hz (E4), and 392 Hz (G4), which form a major triad. This means, essentially, that the tones construct a simple chord (i.e., they are not dissonant). In some conditions, all pulse trains were presented at different frequencies, and in some conditions two pulse trains were presented at one frequency, while the third contrasted. (In these cases, the frequencies used were 252 Hz and 392 Hz.) Also, there were no-contrast conditions, in which all pulses were at 330 Hz. Several rates of presentation were used, and trials were 90 minutes long.

The two main interpretations by subjects were cross-rhythms and meter responses, and Handel and Lawson were able to categorize subjects' responses, based on which conditions were being responded to. One group consisted of responses to those conditions in which the pulse trains were all at differing frequencies and those in which pulse trains were all at the same frequency. The second group consisted of responses to conditions in which two pulse trains were presented at one frequency, while the third was at a contrasting frequency. The second group illustrated the effect of pitch contrast in rhythm interpretation. Each polyrhythmic configuration yielded different response patterns and were discussed individually.

The 2×3×7 configuration can be used to illustrate pitch-contrast effects. Two interpretation strategies were found for this configuration. One was to tap a 2×3 cross-rhythm in all cases. The other included more rhythmic interpretations. For the all-same and all-different pitch conditions, subjects followed the seven-pulse train at slower rates and tapped a 2×3 cross-rhythm or a three-pulse train meter at faster rates. For the contrastor conditions, in which one pulse train was presented at a contrasting frequency, the seven-pulse train was followed at slower rates. At faster rates, a 2×3 cross-rhythm was tapped if the seven-pulse train was the contrastor, and if the two- or three-pulse train was the contrastor, a meter based on the contrastor was tapped.

Handel and Lawson emphasized that any theory of rhythm interpretation must be based on a specific rhythmic configuration, since each configuration elicits a unique response pattern.

Timing was an important factor, with subjects using faster meters and cross-rhythms at slower repetition rates and slower meters at faster rates. Also, the inter-element-timing window of 200-800 ms determined which pulse trains were available to carry the rhythm.

The role of a contrasting-pitch pulse train was shown, with subjects sometimes choosing to follow the contrastor, particularly at faster presentation rates. The contrastor could also strengthen a cross-rhythm made up of the two identical-frequency pulse trains.

Pitch itself was also important. Subjects preferred to tap to the lower-pitch elements (especially for the 3×4×5 configuration).

• Experiment 3

This experiment dealt with pulse duration in two-pulse-train polyrhythms. Two frequencies were used: 440 Hz (A4) and 586 Hz (D5). Pulse trains were either presented at the same frequency or contrasted, such that one pulse train was at 440 Hz and the other was at 586 Hz.

Pulse durations were either one half the inter-element interval, in which case pulse lengths in a polyrhythm differed depending on how many pulses were in a particular pulse train, or were kept consistent at 25 ms. The longer pulses consisted of a 40 ms linear amplitude attack, with a linear amplitude decay for the remainder of the pulse, and the shorter 25 ms pulses consisted of a 12.5 ms linear attack and a 12.5 ms linear decay.

Several types of “frequency-duration” conditions were used, with only frequency variations, only duration variations, and variations of both frequency and duration.

Handel and Lawson determined that the duration of pulses had minor and inconsistent effects on rhythm perception. When pulse-train frequencies were the same, pulses of shorter duration were preferred. But when frequencies differed, duration had no effect. Essentially, pulse duration only affected rhythm interpretation when other cues were not present, that is, when timing constraints were met and all pitches/frequencies were the same.

• Experiment 4

Intensity accentuation was investigated in this fourth experiment. Intensity accentuation refers to some pulses in a polyrhythm being presented at a higher amplitude than others. A 4×5 polyrhythm was used, and pulse trains were separated by the musical interval of a fourth (with one pulse train at 440 Hz and one at 586 Hz–that is, A4 and D5). Accentuated and unaccentuated elements were separated by 15 dB SPL. Either one pulse train or both pulse trains received accents, and there were a variety of accent conditions.

Accents took over when they were available; when one pulse train was accented it served as the meter, and pitch only modified this overall pattern. Handel and Lawson showed that intensity accentuation is an important determinant of perceived rhythm, determining perception either by itself or in combination with pitch and timing factors.

• Experiment 5

The final experiment in Handel's and Lawson's paper extended the investigation of intensity accentuation to three-pulse-train polyrhythms. One polyrhythmic configuration was used in this experiment–the 3×4×5. Pulse trains were either presented with no frequency contrast or were presented with one pulse train at a contrasting frequency. Several repetition rates were used, and a variety of intensity accentuation conditions were employed. Unaccented and accented pulses were separated by 15 dB SPL, and each session lasted 90 minutes.

This time, there was only one dominant response pattern across subjects. Intensity accentuation affected rhythm interpretation, but in a complex way, and often in combination with other factors. Generally, any characteristic which made a pulse train stand out resulted in utilization of that pulse train in the interpretation of the rhythm. Handel and Lawson showed that a variety of factors contribute to determining rhythm perception, which, in this experiment, included intensity accentuation, pitch, intensity and pitch together, and timing factors. All these cues acted within timing constraints (inter-element intervals of 200-800 ms).

Cross-rhythms were greatly reduced in this experiment compared with experiment 2, showing that intensity accentuation made same-pitch pulse trains dissimilar, so their combination was less likely. Intensity strongly influenced rhythm interpretation.

• General discussion

Referring to the 1981 paper of Handel and Oshinsky (discussed above), Handel and Lawson stated that the contextual nature of rhythm interpretation was shown with respect to tempo, and that in this (1983) paper, the same was shown with respect to other factors, namely configuration, frequency, element intensity and element duration. Each of these factors influences interpretation, but depends on the other factors for its precise effect. "Individual differences" are also noted as influencing the effects of these factors.

Rhythm, say Handel and Lawson, comes from the "interplay" of "levels," in these cases represented by pulse trains. Each level is both figure and ground, both part of the overall rhythm and part of the "supporting framework" for the other levels.

Handel and Lawson state that there are two basic factors–timing and configuration–which affect rhythm perception.

Changes in presentation rate affect timing, or inter-element interval, and lead to consistent changes in rhythmic interpretation. Cross-rhythms and fast meters are used at slower rates, which are characterized by longer inter-element intervals, and slow meters and unit responses are seen at faster rates with shorter inter-element intervals. Motor constraints may affect one's ability to synchronize with faster pulse trains or cross-rhythms at faster presentation rates, yet there were exceptions to the previously stated pattern, in which subjects tapped to pulse trains even when inter-element intervals were less than 200 ms, observed in these experiments (Handel and Lawson, 1983).

A pulse train can do more than one thing. It can serve as a time keeper in the background, as a way of structuring the other pulses. This happens mostly when inter-element intervals are between 200 ms and 800 ms. A pulse train can also be foreground, as in cross-rhythms.

Configuration relates to pulse train-pulse train and pulse train-pitch relationships. If pulse-train rates were similar and pitch was available as a cue, subjects used pitch to help interpret the rhythms, usually following the low-pitch pulse train. Additionally, the particular relationships among pulse-train rates can influence the type of interpretation used. This can be illustrated by comparing responses to the 2×3×7 configuration with responses to the 2×5×7 configuration. In the 2×3×7 configuration, a popular response was to tap a 2×3 cross-rhythm. The 2×5 cross-rhythm, however, was rarely used.

It seems that, as a result of the very different rate of progression of the seven-pulse train in the 2×3×7 configuration, the similarity of the two- and three-pulse trains was emphasized, resulting in their easy combination. However, the seven-pulse train in the 2×5×7 configuration was similar in rate to the five-pulse train, which was pulled away perceptually from the two-pulse train, making it much less likely for a cross-rhythm based on the two- and five-pulse trains to be utilized.

Configuration also affects how the cues of pitch and intensity are used. For instance, when cross-rhythms were popular for a particular configuration and a contrasting-pitch pulse train was part of the cross-rhythm, that cross-rhythm became less popular; however, if the contrasting-pitch pulse train was *not* a part of the cross-rhythm, the cross-rhythm became more popular.

Handel and Lawson express the view that, due to the lack of any basic rhythmic units and the complex interactions of factors involved in rhythm interpretation, generalizations about rhythm perception may not be possible. They urge for theories which predict a range of possibilities based on the interaction of characteristics of rhythmic patterns.

Pitch contrast

In 2005, two researchers in the Netherlands, Dirk Moelants and Leon van Noorden, published an article in which the combined effect of pitch contrast and tempo difference in two-pulse-train polyrhythms was explored.

The researchers were interested in "streaming," or "fission," effects in pattern perception. "Streaming" is a term used by Bregman, while "fission" is van Noorden's term. Both refer to simultaneous auditory "streams," or lines, being heard as separate events. One factor which influences whether this occurs is pitch contrast between the auditory streams; with small pitch contrasts, a single unit is more likely to be heard (that is, fission/streaming is less likely) (Moelants and van Noorden, 2005).

Moelants and van Noorden proposed that using larger pitch intervals than those used by Handel and others would result in more streaming. A "resonance model for temporal selectivity" was also described, but it needn't be discussed here.

Three two-pulse-train polyrhythms were presented at a variety of repetition rates and with three levels of pitch contrast. There were small-contrast conditions, in which one pulse train was presented at 440 Hz while the other was presented at 466 Hz - a difference of one semitone, which is near the “fission boundary” according to Moelants and van Noorden. The medium-contrast conditions had one pulse train at 440 Hz and one at 586 Hz - a difference of five semitones, or a musical fourth (this is the interval commonly used by Handel and collaborators). In the large-contrast conditions, one pulse train was presented at 220 Hz and the other was presented at 1172 Hz. The difference here is of 29 semitones, or a fourth plus two octaves.

Subjects tapped the rhythm on a computer-keyboard spacebar during each 20 s rhythm presentation. They were allowed to listen and tap again or continue to the next polyrhythm. Data were coded visually by overlaying dots representing taps on a “grid” in which each line represented a polyrhythm pulse.

Unit responses (tapping once per pattern repetition) became less popular as pattern repetition rate decreased, showing a strong effect of tempo. Unit responses also decreased as pitch interval increased.

Moelants and van Noorden removed unit responses and compared responding to fast and slow pulse trains. It was found that polyrhythm configuration affects meter preference. Subjects showed a preference for either a meter based on the slower pulse train or a meter based on the faster pulse train, depending on the configuration of the polyrhythm.

Presentation rate still affected meter perception, with slower meters preferred at faster presentation rates and faster meters preferred at slower rates. In the small-contrast conditions, subjects preferred a fast meter, and this switched to a preference for a slow meter with increased pitch contrast.

Moelants and van Noorden compared relative responding to high and low pitches, finding that pitch interval had no statistically significant effect. However, a low-pitch preference was observed in the small- and medium-contrast conditions, while no pitch preference was seen in the large-contrast conditions.

Large pitch intervals weaken the overall pattern and the "interaction of the coinciding tones," say Moelants and van Noorden, which explains the decrease in unit responses as frequency contrast increases.

Summary: Factors affecting rhythm perception

Foundations

Rhythm research has been concerned primarily with three issues: the range of consciousness, psychophysics and kinesthetics. The range of consciousness relates to perceptual grouping, while kinesthetics addresses whether movement is required for the perception of rhythm. Psychophysical research investigates rhythm perception by altering the physical characteristics of stimuli. This is the area of research which receives primary focus here.

Factors

Multiple factors affect perception of rhythm, and two types of response have dominated polyrhythm research in this area. These are "meter responses," in which a person follows each pulse in one pulse train, and "cross-rhythms," in which all pulses in two or more pulse trains are followed (Handel & Lawson, 1983 & Handel, 1984).

• Inter-element Interval

If the inter-element interval–the amount of time between the onset of an element, or pulse, and the onset of the following element–is greater than about 800 ms, elements tend to be perceived as unrelated events. On the other hand, if element onsets are separated by less than approximately 200 ms, the elements are not perceived individually, but as groups with subjective accents. Preference for a pulse train drops dramatically when its inter-element intervals are without these bounds.

Cross-rhythms tend to be preferred at slower rates and for simpler polyrhythms, while meter responses are preferred at faster rates (Handel, 1984). Interestingly, Bolton (1894) found that the rate of clicks, or beats, at which rhythmical grouping ceases is close to 10 per second, which reflects an inter-element interval of about 100 ms; this is just below the rate mentioned at which beats begin to be perceived not as distinct pieces, but as grouped into chunks. This is, according to Bolton, also near the lowest rate of air vibrations at which a tone begins to be heard, meaning also that no distinct pieces are heard at rates faster than this. Bolton also states that the upper inter-element-interval limit for rhythmic grouping is about 1.58 seconds, which is of course a bit longer than Handel's 800 ms interval. Keep in mind, though, that Handel's and Bolton's subjects were performing different tasks.

Dwight W. Miles (1937) found similar values–0.16 to 0.663 seconds per inter-response interval–while studying preferred tapping rates. This range of values is quite close to Handel's interval.

• Pitch

Consider a three-pulse-train polyrhythm. If two pulse trains are of identical frequency and one is different, then the “contrastor” is preferred by some subjects. Other subjects choose a same-pitch cross-rhythm. In many situations, particularly when timing constraints (200-800 ms inter-element interval discussed above) are met, the low-pitch pulse train is preferred (Handel, 1984).

• Configuration

For two-pulse-train and three-pulse-train polyrhythms, relative tempos affect when a particular pulse train is preferred. If all timing constraints are satisfied, pitch-based meters are only used for polyrhythms with pulse trains proceeding at about the same rate (Handel, 1984). The configuration can affect the types of interpretations employed (meter responses, cross-rhythms, etc.) and the roles of each pulse train, as seen in the differing interpretations of the 2×3×7 and 2×5×7 polyrhythms.

• Quality

Handel and Lawson studied two qualities: duration and intensity. Durational accenting of elements has minor and inconsistent effects. Intensity, though, is a “dominant cue to rhythmic interpretation,” (Handel, 1984) but its effect is also a function of other factors, such as timing and pitch. Overall, duration and intensity accents reduce the use of cross-rhythms (Handel & Lawson, 1983; Handel, 1984).

• Individual Differences

Lastly, there is the factor of individual differences. There seems to be subject consistency and between-subject differences, overall. Those who prefer cross-rhythms tend to prefer them across polyrhythms, and those who prefer meter responses also tend to prefer them across polyrhythms. The configuration of the polyrhythm, though, determines *which* one of each is used (which cross-rhythm, which meter response) (Handel, 1984).

This experiment attempts to recapture some of the findings reported by Handel et al., and by Moelants and van Noorden, such as the tendency of subjects to tap to the lower pitch and slower pulse trains, and to extend the investigation to three-pulse-train polyrhythms. Pitch effects in polyrhythm meter perception have been most clearly shown when inter-element intervals in all pulse trains are between 200 ms and 800 ms. Polyrhythms in this experiment were designed with these limits in mind, in order to further investigate pitch effects in three-pulse-train polyrhythms. Three two-pulse-train polyrhythms and three three-pulse-train polyrhythms were used, and the length of each presentation was set at 15 seconds, in order to avoid fatiguing subjects. Three types of pitch-contrast conditions were employed. Rhythms were presented and subjects were asked to tap the meter.

Chapter 2

Method

Participants

There were 31 participants, 11 females and 18 males, all students at The University of Tennessee. Nearly all participants were students in introductory Psychology classes. The others were graduate Psychology students. Data from 21 of the participants were usable, meaning that at least 75% of each of these participants' responses were codable by the conventions described in *Analysis*, below. There were six females and 15 males in the usable group.

Apparatus

Pulse trains were created with *Cool Edit Pro* v2.0 sound-production/editing software. Pulse trains were loaded into a sequencer in Propellerhead's *Reason* v3.0 music-production/editing software, which was used to assemble and organize the polyrhythms. Trials were run in *Reason*.

Responses in each trial were recorded as a track in the trial file using M-Audio's *Trigger Finger* MIDI (Music Instrument Digital Interface) controller. Rhythms were presented monaurally to participants through headphones in a sound-attenuated room.

Procedure

All pulse trains were composed of 70-ms pulses, each pulse having a 35-ms linear amplitude attack and a 35-ms linear decay. (Open Attachments and play the “3 C4" file to hear a three-pulse train.)

Six polyrhythmic configurations were used. Three were two-pulse-train polyrhythms, and three were three-pulse-train polyrhythms. The two-pulse-train polyrhythmic configurations were: 2×5, 2×7 and 3×4, and the three-pulse-train polyrhythmic configurations were: 2×3×7, 2×5×7 and 3×4×5. Three tones/frequencies were used to make up three types of frequency conditions for each polyrhythmic configuration. The first frequency condition was a no-contrast condition in which all pulses in the polyrhythms were at musical note C4 (262 Hz).

The second type of frequency condition was a low-contrast condition which, in the case of the two-pulse-train polyrhythms, consisted of one pulse train being presented at C4 while the other was presented at G4 (392 Hz). (Open Attachments and play the "25_LC_5hi" file to hear a 2×5 polyrhythm with the five-pulse train at the higher (392 Hz) frequency, looped twice.)The frequencies were counterbalanced, so that each pulse train was presented at each frequency. In the case of the three-pulse-train polyrhythms, two pulse trains were presented at C4 while the third was presented at G4, and two pulse trains were presented at G4 while the third was presented at C4, counterbalancing the frequencies. Each pulse train served as the contrastor (*i.e.* the single pulse train whose frequency differs from the other two) in both arrangements.

The third type of frequency condition was a high-contrast condition in which the musical notes used were C4 and G6 (1568 Hz). The conditions were the same as in the low-contrast group. (Open Attachments and play the "345_HC_4hi" file to hear a high-contrast 3×4×5 polyrhythm with the four-pulse train at the higher (1568 Hz) frequency, looped twice.) Table 1[1] shows the high-contrast frequency conditions for a 3×4×5

[1]All tables and figures are located in the Appendices.

polyrhythm. There were 54 distinct polyrhythms in all.

All polyrhythms were presented at a rate of 1.5 s per pattern repetition. Thus, pulses in a two-pulse train recurred at 750-ms intervals, and those in a seven-pulse train at 214-ms intervals. Polyrhythms were presented for 15 seconds (10 pattern repetitions) each. Six seconds of silence preceded each polyrhythm. Sessions lasted approximately 19 minutes, with each polyrhythm being presented once.

Subjects were given a “Concepts and Instructions” sheet which explained the concept of meter, giving an example, and gave the task, which would be to tap the meter of each polyrhythm as it was being heard. A copy of the Concepts and Instruction sheet can be found in Appendix C. Subjects then entered the sound-attenuated room and were seated in a chair in front of a table on which were the *Trigger Finger* MIDI device and a pair of headphones. Subjects donned the headphones and the door to the room was closed. Upon the subject’s signaling that they were ready to begin, the experimenter started the session.

Analysis

Sessions were coded in *Reason* v3.0, which allowed responses to be examined by sound and visually. In order for a response to be counted, the subject must have tapped the same meter for at least two repetitions of the rhythmic pattern. The first two (of the ten) pattern repetitions of each polyrhythm were not counted, in order to give the subject time to listen before responding. If multiple meters were tapped during one polyrhythm presentation, the meter which was tapped the most was coded. If no one meter was more represented than any other, the meter which was tapped last (of the most represented meters) was coded.

Taps which coincided with every-other pulse in a pulse train were coded as a meter based on this pulse train. When a subject's taps coincided with every-other pulse in a pulse train made up of an odd number of pulses, the taps during successive pattern repetitions would alternate in number, with either one more or one less tap in each repetition. (Ex.: For a seven-pulse train, the pattern of tapping would be 3-4-3-4.) The alternating number of taps must have occurred across at least four pattern repetitions to be coded as a response.

This coding rule was followed in all but one case: when a two-pulse train was presented and the subject tapped once per pattern repetition. This type of response (tapping once per pattern repetition) was always coded as a "unit" response, that is, a meter based on the entire pattern. If the subject tapped double the number of pulses in a presented pulse train, the meter coded was that of the doubled pulse train. The coding of meters when taps don't correspond to each pulse in the coded pulse train takes into account the tendency for people to perceptually group successive identical sounds (Fraisse, 1963). A person may tap to the groupings, not to each element in the groupings.

The procedure of presenting subjects with auditory polyrhythms, instructing them to tap the meter on a key, then recording those taps for subsequent coding, was previously used by Handel and Oshinsky (1981), Handel and Lawson (1983) and others.

Chapter 3

Results

Responses from males and females were analyzed separately, for the groups' general response patterns were different. (The gender × dependent variable test was significant [$\chi^2(10, N=1065)=85.850, p<.001$], and males gave many more unit responses – tapping once per pattern repetition – than did females.) All analyses are chi square, using Fisher's Exact Test, and employing the Monte Carlo method when necessary. It must be acknowledged that chi square analyses may not have been necessary, or even appropriate, for these data, as each response in a chi square analysis is taken as independent of any other response and any responder/subject. Of interest, however, were response patterns in general, and chi square provided a relatively easy way of seeing that and of setting up the comparisons.

Females

There was a significant overall effect of contrastor in three-pulse-train polyrhythms [$\chi^2(1, N=203)=6.744, p=.011$], wherein the contrastor was preferred. The effect of contrastor × tempo was significant [$\chi^2(4, N=203)=52.567, p<.001$], wherein a general preference for the contrastor was shown, with subjects choosing the contrastor most often when it was also the slowest-progressing pulse train. The slowest-progressing pulse train was chosen most often when a non-contrasting pulse train served as the meter as well. The effect of contrastor × pitch was significant [$\chi^2(3, N=203)=48.958, p<.001$]. Subjects here generally preferred the contrastor, most often when it was the low-pitch pulse train. The low-pitch pulse train was also preferred when subjects did not choose the contrastor. There was no significant effect of contrastor × configuration or contrastor × contrast condition.

Contrast condition × tempo in two-pulse-train polyrhythms was significant [$\chi^2(8, N=90)=15.004, p=.029$], as was contrast condition × tempo in three-pulse-train polyrhythms [$\chi^2(10, N=234)=23.895, p=.008$]. For two-pulse-train polyrhythms, subjects preferred the slower-progressing pulse train in both high- and low-contrast conditions, while the faster- and slower-progressing pulse trains were about equally preferred in the no-contrast conditions. For three-pulse-train polyrhythms, subjects preferred the slowest-progressing pulse train in the high-contrast conditions, and showed equal preference for the slow- and medium-progressing pulse trains in the low-contrast conditions. Unit responses and the slower-progressing pulse train were about equally preferred in the no-contrast conditions. Contrast condition × pitch was not significant in either two- or three-pulse-train polyrhythms.

The configuration × tempo interaction was significant in three-pulse-train polyrhythms [$\chi^2(10, N=234)=26.884, p=.002$], but not in two-pulse-train polyrhythms. In the three-pulse-train polyrhythms, subjects preferred the slowest-progressing pulse train for the 2×3×7 and the 2×5×7 polyrhythms, while preferring the medium-progressing pulse train for the 3×4×5 polyrhythm. There was no effect of configuration × pitch in either two- or three-pulse-train polyrhythms.

There was an overall effect of pitch in both two- and three-pulse-train polyrhythms, [$\chi^2(1, N=60)=5.4, p=.027$] and [$\chi^2(1, N=174)=4.506, p=.040$], respectively. Subjects preferred the low-pitch pulse train in both cases. The interaction of pitch and tempo was significant in two-pulse-train polyrhythms [$\chi^2(1, N=60)=4.97, p=.042$], where subjects preferred the slower pulse train, especially when it was presented at the lower pitch. The interaction was not significant in three-pulse-train polyrhythms. (These tests only considered instances in which either the higher- or lower-pitch pulse train was chosen; unit responses and the no-contrast conditions were not considered.)

There was an overall effect of tempo in both two- and three-pulse-train polyrhythms, [$\chi^2(2, N=64)=66.5, p<.001$] and [$\chi^2(3, N=197)=60.442, p<.001$], respectively. Subjects preferred the slowest-progressing pulse train in both cases.

Generally, females preferred the contrasting pulse train when available, and preferred to tap to the slower and low-pitch pulse trains. Table 2 shows some representative examples of response patterns, and Table 3 summarizes response patterns.

Males

There was a significant overall effect of contrastor in three-pulse-train polyrhythms [$\chi^2(1, N=511)=7.767, p=.006$], with subjects preferring a meter not based on the contrasting pulse train. The effect of contrastor × tempo was significant [$\chi^2(4, N=511)=287.979, p<.001$], as was the effect of contrastor × pitch [$\chi^2(3, N=511)=283.718, p<.001$]. Both cross-tabulations showed a preference for unit responses, followed by a general preference for the contrastor. There was no significant effect of contrastor × configuration or contrastor × contrast condition.

Contrast condition × tempo in two-pulse-train polyrhythms was significant [$\chi^2(8, N=225)=28.601, p<.001$], with subjects preferring the slower-progressing pulse train in the high- and low-contrast conditions and unit responses in the no-contrast conditions.

Contrast condition × tempo in three-pulse-train polyrhythms was also significant [$\chi^2(10, N=585)=21.581$, $p=.023$], with subjects preferring unit responses across all conditions. Contrast condition × pitch was significant in two-pulse-train polyrhythms [$\chi^2(4, N=180)=10.133$, $p=.023$], but not in three-pulse-train polyrhythms. In two-pulse-train polyrhythms, the lower-pitch pulse train was preferred for the high-contrast conditions, while the lower-pitch pulse train and unit responses were equally preferred in the low-contrast conditions.

The configuration × tempo interaction was significant in three-pulse-train polyrhythms [$\chi^2(10, N=585)=37.926$, $p<.001$], but not in two-pulse-train polyrhythms. Unit responses were preferred for all configurations of the three-pulse-train polyrhythms. There was no effect of configuration × pitch in two-pulse-train polyrhythms, but there was an effect in three-pulse-train polyrhythms [$\chi^2(8, N=585)=24.298$, $p=.003$], where unit responses were again preferred.

There was an overall effect of pitch in both two- and three-pulse-train polyrhythms, [$\chi^2(1, N=125)=6.728$, $p=.012$] and [$\chi^2(1, N=299)=6.184$, $p=.015$], respectively. In both set of cases, subjects preferred the lower-pitch pulse train. There was no significant interaction of tempo and pitch. (These tests only considered instances in which either the higher- or lower-pitch pulse train was chosen; unit responses and the no-contrast conditions were not considered.)

There was an overall effect of tempo in both two- and three-pulse-train polyrhythms, [$\chi^2(2, N=168)=47.036$, $p<.001$] and [$\chi^2(3, N=501)=92.733$, $p<.001$], respectively. The slower-progressing pulse train was preferred for two-pulse-train polyrhythms, while unit responses were preferred for three-pulse-train polyrhythms.

The overwhelming preference for males was to tap unit responses. A preference for meters based on the slower pulse train was sometimes observed in two-pulse-train polyrhythms. Table 2 shows some representative examples of response patterns, and Table 3 summarizes response patterns.

Chapter 4

Discussion

Females

Females consistently chose the slow and low-pitch pulse trains, and preferred the contrastor when available. Another way of saying this is that subjects' perceptions of meter tended to match the pulse train which was presented at a unique pitch, when there was such a pulse train, and to match the pulse train which was slowest and/or lower in pitch within a polyrhythm. The pattern was strengthened when the contrastor was the slower and/or low-pitch pulse train. The one exception to this pattern was the preference for the four-pulse train in the 3×4×5 polyrhythmic configuration. Reasons for the subjects' preference for the medium-progressing pulse train in the 3×4×5 rhythmic configuration are unclear, but perhaps it (the four-pulse train) provided an anchor and a way of relating the faster five-pulse train and the slower three-pulse train.

As far as the preference for the contrasting pulse train, the fact of being a single pulse train at a contrasting pitch along side two other pulse trains of the same pitch may make the former more figural for listeners. Conversely, the cacophony of two pulse trains presented at the same pitch may constitute a background against which the contrastor is readily apparent.

Responses from females to two- and three-pulse-train polyrhythms were similar, with preferences being shown in both sets of cases for slow and lower-pitch pulse trains. Multiple factors, including pitch and relative pulse-train tempo, influence meter perception.

Higher levels of pitch contrast had almost no differential effect, compared to lower levels, on the perception of meter. Making the medium-progressing pulse train less perceptually available to serve as the meter in three-pulse-train polyrhythms was the only observable consequence of higher pitch contrasts.

Males

Males, as a group, preferred meters not based on the contrasting pulse train, and generally tapped unit responses across conditions. These least differentiated perceptual responses were especially popular for three-pulse-train polyrhythms, while low-pitch and slower-progressing pulse trains were preferred, along with unit responses at times, for two-pulse-train polyrhythms.

Meter perception of two-pulse-train polyrhythms may be more malleable than that of three-pulse-train polyrhythms. This may be owing to the greater perceptual complexity of three-pulse-train polyrhythms, which might encourage in some cases a type of response that allows for easier integration of all the parts of a polyrhythm (such as unit responses). Unit responses to two-pulse-train polyrhythms occurred mostly in the absence of (strong) pitch cues, that is, in the no-contrast conditions (and low-contrast conditions), while unit responses were the dominant response type in most cases to the three-pulse-train polyrhythms, regardless of the availability of pitch cues.

As for the difference in responding in cases of higher and lower pitch contrast, a higher level of pitch contrast seemed only to affect perception of two-pulse-train polyrhythms, by resulting in fewer unit responses than were found in cases of lower pitch contrast. This was observed previously by Moelants and van Noorden (2005). Perhaps pitch contrast in the two-pulse-train polyrhythms became a strong enough cue in situations with large pitch differences among pulse trains to draw attention to the individuality of those pulse trains. This again points to the greater malleability of meter perception of two-pulse-train polyrhythms, as opposed to those made up of three pulse trains, so that, while more interpretations are possible for three-pulse-train polyrhythms, the specific interpretation used may be less likely to be influenced by pitch cues.

General pattern

When the patterns of responses were examined without regard to unit responses, males and females responded in the same way in nearly every case. Also, unit responses – the dominant type of response from males – were not absent from the responses of females. Figures 1 and 2 show examples of the similarities and differences in the response patterns of females and males. These observations perhaps point to organizational activity in styles of perceiving for individuals in novel situations, more than strict differences between males and females.

So, while some individuals chose to respond in the least perceptually differentiated way, many others responded in ways which indicate that they were attending to aspects of, and within, the entire polyrhythmic organization. Now, neither of these styles is better or worse than the other, they simply reflect different perceptual perspectives, so to speak.

The concepts of analytic and synthetic listening (from audiology and musicology) can be applied here. These terms are used when discussing perception of complex tones and events in rapid succession. The analytic listener ascribes more perceptual weight to a particular aspect of an organizational whole, while the synthetic listener gives each component of the overall pattern equal perceptual weight, thereby attending to the pattern as a whole. Unit responses can be conceived as evidence of synthetic listening, with the subject attending to the overall pattern. Other meter-type responses can be conceived as evidence of analytic listening, with the subject focusing on one component of the rhythmic pattern.

It might be possible, through altering the instructions given to participants in this experiment, to elicit one type of response from everyone. As can be seen from the instruction sheet (in Appendix C), the only restriction, really, is to tap metrically. Unit responses might be elicited by instructing participants to attend and tap to the overall pattern, integrating its different parts. On the other hand, more perceptually differentiated responses might be obtained with instruction to tap to the most perceptually salient aspect of those which comprise the overall rhythmic pattern.

Self-selection may be an issue in considering these response patterns. Subjects volunteered for this experiment, and perhaps those who were more interested in this particular research were more likely to participate. Of more concern, though, is the possibility that those who were more interested in gaining extra credit points in their Introduction to Psychology classes were over-represented in this data set.

As far as the issue of the larger proportion of female participants who’s data couldn’t be used, it is possible that females were more likely to just give up attempting to respond when rhythms were more complex. Or, they may have responded in confused or inconsistent ways in these cases. Males, on the other hand, were perhaps more likely to give unit responses when rhythms were more complex, contributing to the large number of unit responses in their response pattern, and resulting in a larger proportion of their data being usable.

Some of these findings agree with those of previous research, namely, that multiple factors (pitch, tempo) affect meter perception (Handel & Oshinsky, 1981); some subjects prefer a contrasting-pulse-train-based meter (Handel & Lawson, 1983); and subjects tend to prefer the slowest pulse train to serve as the meter, as observed with two-pulse-train polyrhythms (Moelants & Van Noorden, 2005).

This research addressed meter perception in three-pulse-train polyrhythms with large pitch contrasts and revealed that three-pulse-train polyrhythms with large pitch contrasts do not result in notably different meter perceptions from those with smaller pitch contrasts. Preferences when dealing with complex rhythms are influenced more by the overall complexity of the pattern than by any individual characteristics of the rhythms, and different perceptual-organizational styles are reflected in response types.

Limitations

Factors, such as timbre and intensity accents, which previously have been shown to affect meter perception, (Handel & Oshinsky, 1981) were not addressed here.

The experimental apparatus employed here excluded the realistic possibility of allowing cross-rhythm responses. While this may be considered a limitation because it restricted the freedom of subjects to respond in whatever way they preferred, the phenomenon of greatest interest in this experiment was *meter* perception specifically. Also, if Handel and Lawson (1983) are correct that meter responses and cross-rhythms represent opposite sides of the same organizational activity, then perhaps the drawback is minimal.

The specificity of this research does not allow for sweeping generalizations to be made about rhythm perception. Additionally, the rhythms used in this experiment are not particularly musical, so our findings likely tell us more about how we deal with auditory patterns generally than about how we deal with musical rhythms in particular. Only a small portion of the larger rhythm picture has been revealed. Opportunities for further work seem almost inexhaustible, provided one can tolerate the tedium and complexity that inevitably will be encountered.

Final Remark

The time constraints of the social world and of the earth provide a framework for our experiences and actions. Without this framework, we would be confused and adrift (Fraisse, 1963). In the same way, meter provides a framework for rhythms. This experiment can be seen as a compression of this phenomenon; subjects apply a temporal frame upon which the other events in the polyrhythm rest, giving them a form to which they may be tethered.

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APPENDICES

Appendix A

Table 1. High-Contrast Frequency Conditions for a 3×4×5 Polyrhythm

Condition	3-Pulse Train	4-Pulse Train	5-Pulse Train
1	C4	C4	G6
2	C4	G6	C4
3	G6	C4	C4
4	G6	G6	C4
5	G6	C4	G6
6	C4	G6	G6

Table 2. Representative Examples of Response Patterns

	Contrastor × Pitch			
	Females		Males	
	Contrastor	Non-Contrastor	Contrastor	Non-Contrastor
Unit	N/A	23 (11%)	N/A	202 (40%)
Low Pitch	69 (34%)	32 (16%)	124 (24%)	47 (9%)
High Pitch	51 (25%)	22 (11%)	100 (20%)	28 (5%)

	Contrast Condition × Tempo in Three-Pulse-Train Polyrhythms					
	Females			Males		
	No Contrast	Low Contrast	High Contrast	No Contrast	Low Contrast	High Contrast
Unit	7 (3%)	17 (7%)	6 (3%)	28 (5%)	107 (18%)	95 (16%)
Slow	9 (4%)	37 (16%)	49 (21%)	7 (1%)	57 (10%)	73 (12%)
Medium	1 (0%)	35 (15%)	30 (13%)	4 (1%)	61 (10%)	58 (10%)
Fast	0 (0%)	11 (5%)	12 (5%)	4 (1%)	22 (4%)	28 (5%)

Table 3. Summary of Response Patterns

Factor(s)	Female	Male
Contrastor	Contrastor preferred	Meter *not* based on contrastor
Contrastor × tempo	Contrastor preferred, especially when slow; slow pulse train also chosen when non-contrastor tapped	Unit response, followed by contrastor, preferred
Contrastor × pitch	Contrastor preferred, especially when low pitch; low-pitch pulse train also preferred when non-contrastor tapped	Unit response, followed by contrastor, preferred
Contrastor × configuration	NS*	NS
Contrastor × contrast condition	NS	NS
Contrast condition × tempo in two-pulse-train polyrhythms	Faster- and slower-progressing pulse trains equally preferred in no-contrast conditions; Slower-progressing pulse train preferred in low- and high-contrast conditions	Unit responses preferred in no-contrast conditions; Slower-progressing pulse train preferred in low- and high-contrast conditions
Contrast condition × tempo in three-pulse-train polyrhythms	Unit response and slower-progressing pulse train equally preferred in no-contrast condition; slow and medium-progressing pulse trains equally preferred in low-contrast conditions; slow pulse train preferred in high-contrast conditions	Unit response preferred across all conditions
Contrast condition × pitch in two-pulse-train polyrhythms	NS	Unit response and lower-pitch pulse train equally preferred in low-contrast conditions; lower-pitch pulse train preferred in high-contrast conditions

*NS=Not Significant

Table 3. Continued

Factor(s)	Female	Male
Contrast condition × pitch in three-pulse-train polyrhythms	NS	NS
Configuration × tempo in two-pulse-train polyrhythms	NS	NS
Configuration × tempo in three-pulse-train polyrhythms	Slowest pulse train preferred for 2×3×7 and 2×5×7, medium-progressing pulse train preferred for 3×4×5	Unit response preferred for all configurations
Configuration × pitch in two-pulse-train polyrhythms	NS	NS
Configuration × pitch in three-pulse-train polyrhythms	NS	Unit response preferred for all configurations
Pitch in two-pulse-train polyrhythms	Low-pitch pulse train preferred	Low-pitch pulse train preferred
Pitch in three-pulse-train polyrhythms	Low-pitch pulse train preferred	Low-pitch pulse train preferred
Pitch × tempo in two-pulse-train polyrhythms	Slower pulse train preferred, especially when at lower pitch	NS
Pitch × tempo in three-pulse-train polyrhythms	NS	NS

*NS=Not Significant

Table 3. Continued

Factor(s)	Female	Male
Tempo in two-pulse-train polyrhythms	Slower pulse train preferred	Slower pulse train preferred
Tempo in three-pulse-train polyrhythms	Slowest pulse train preferred	Unit response preferred

Appendix B

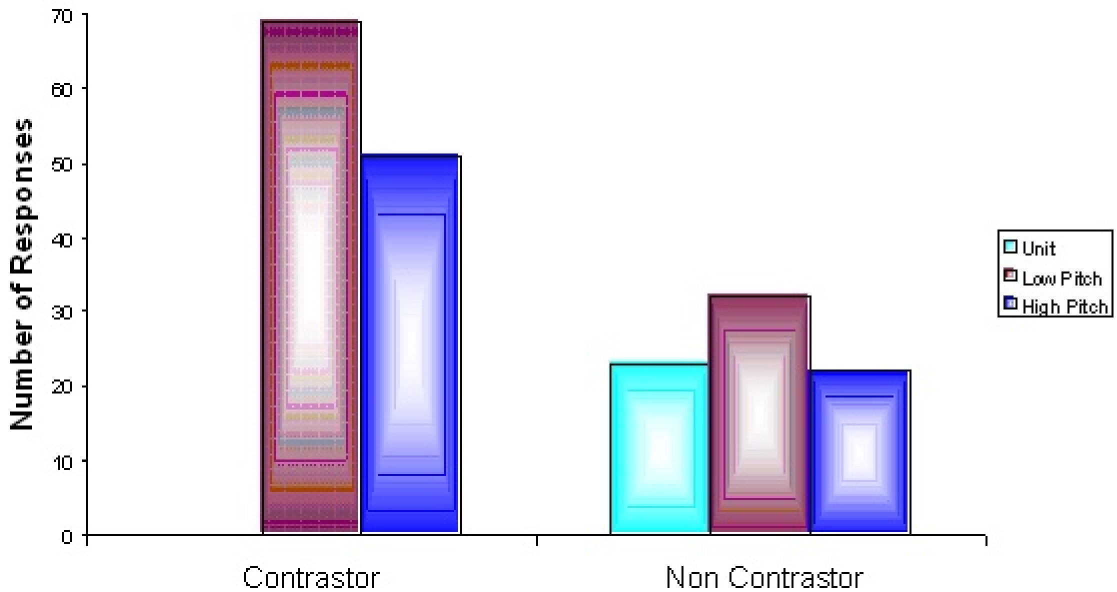

Figure 1. Effect of Interaction of Contrastor and Pitch for Females

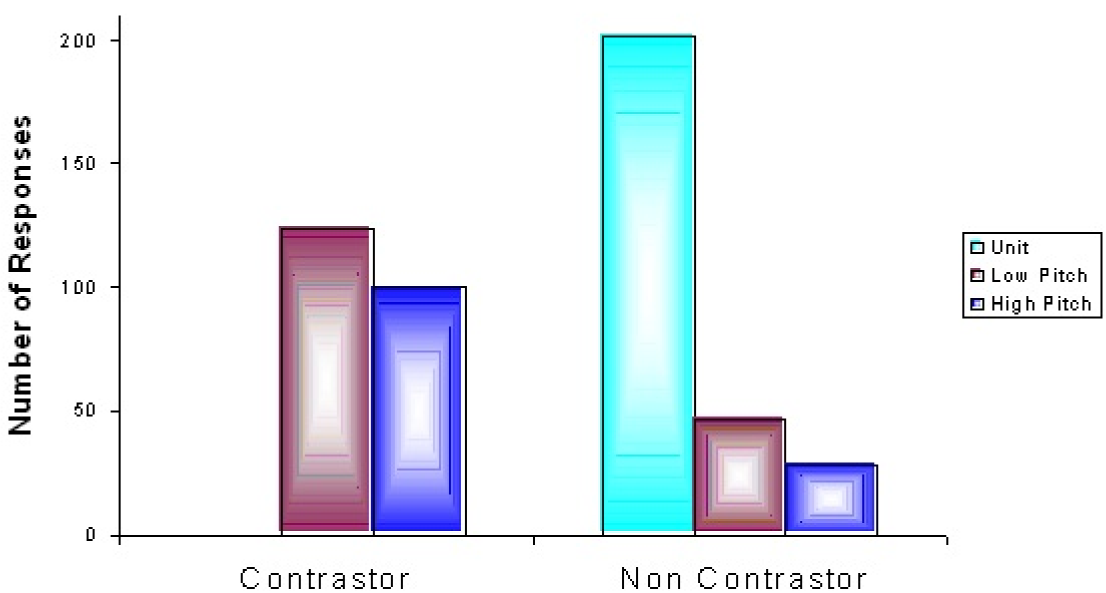

Figure 2. Effect of Interaction of Contrastor and Pitch for Males

Appendix C
Concepts and Instructions

Rhythm- A sequence of events as they occur in time. (The organization of sound in time.)

Meter- Meter is a regularly recurring event in a rhythmic sequence which can serve to help make sense of the rhythm. In order to distinguish between 'rhythm' and 'meter,' you can think of a person in a marching band. This person is playing the rhythm on an instrument while marching the meter. You may also think of a metronome. Musicians use metronomes to keep a steady beat while playing a composition. The beats, or clicks, of the metronome can be thought of as representing the meter of the piece of music being played.

Instructions: In this experiment, you will be presented with a series of auditory rhythmic sequences. There will be a few seconds of silence before the first rhythmic sequence and a few seconds of silence between each sequence. Please tap the meter on the device key as you are listening to each rhythmic sequence. Begin tapping as soon as you are ready during each sequence. Treat each rhythmic sequence individually, and tap firmly. Basically, you are being asked to 'keep time' with each rhythmic sequence.

Vita

Nigel O. Lay was born in Knoxville, Tennessee, on December 18, 1978. His childhood was spent in Oak Ridge, Tennessee, attending elementary school at Cedar Hill and Glenwood Elementary Schools. He attended Jefferson Junior High School and Oak Ridge High School, graduating in 1997. He received his B. A. in psychology with high honors from The University of Tennessee, Knoxville, in 2002, and stayed there to earn his M. A. in experimental psychology in 2008.